

LP2989

Micropower/Low Noise, 500 mA Ultra Low-Dropout Regulator

For Use with Ceramic Output Capacitors

General Description

The LP2989 is a fixed-output 500 mA precision LDO regulator designed for use with ceramic output capacitors.

Output noise can be reduced to 18 μ V (typical) by connecting an external 10 nF capacitor to the bypass pin.

Using an optimized VIP™ (Vertically Integrated PNP) process, the LP2989 delivers superior performance:

Dropout Voltage: Typically 310 mV @ 500 mA load, and 1 mV @ 100 μ A load.

Ground Pin Current: Typically 3 mA @ 500 mA load, and 110 μ A @ 100 μ A load.

Sleep Mode: The LP2989 draws less than 0.8 μ A quiescent current when shutdown pin is pulled low.

Error Flag: The built-in error flag goes low when the output drops approximately 5% below nominal.

Precision Output: Guaranteed output voltage accuracy is 0.75% ("A" grade) and 1.25% (standard grade) at room temperature.

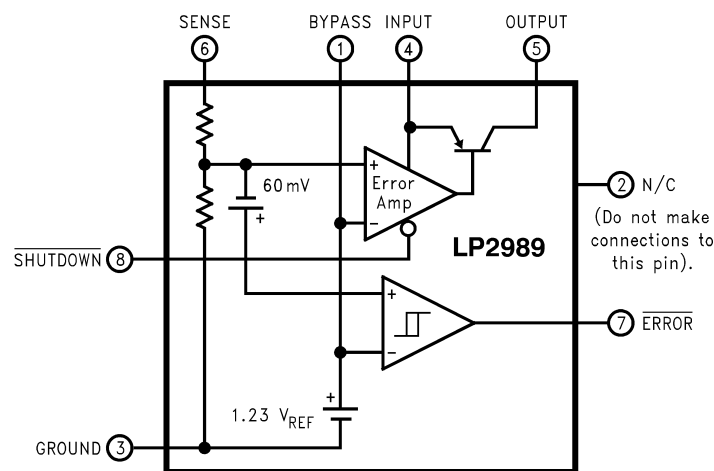
Features

- Ultra low dropout voltage
- Guaranteed 500 mA continuous output current
- Very low output noise with external capacitor
- SO-8 surface mount package
- <0.8 μ A quiescent current when shutdown
- Low ground pin current at all loads
- 0.75% output voltage accuracy ("A" grade)
- High peak current capability (800 mA typical)
- Wide supply voltage range (16V max)
- Overtemperature/overcurrent protection
- -40°C to +125°C junction temperature range

Applications

- Notebook/Desktop PC
- PDA/Palmtop Computer
- Wireless Communication Terminals
- SMPS Post-Regulator

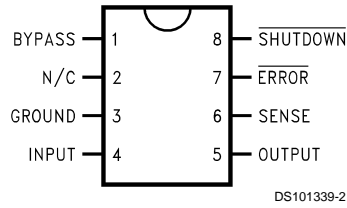
Block Diagram



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Connection Diagram

Surface Mount Packages:
SO-8 Package Type M: See NS Package Drawing Number M08A

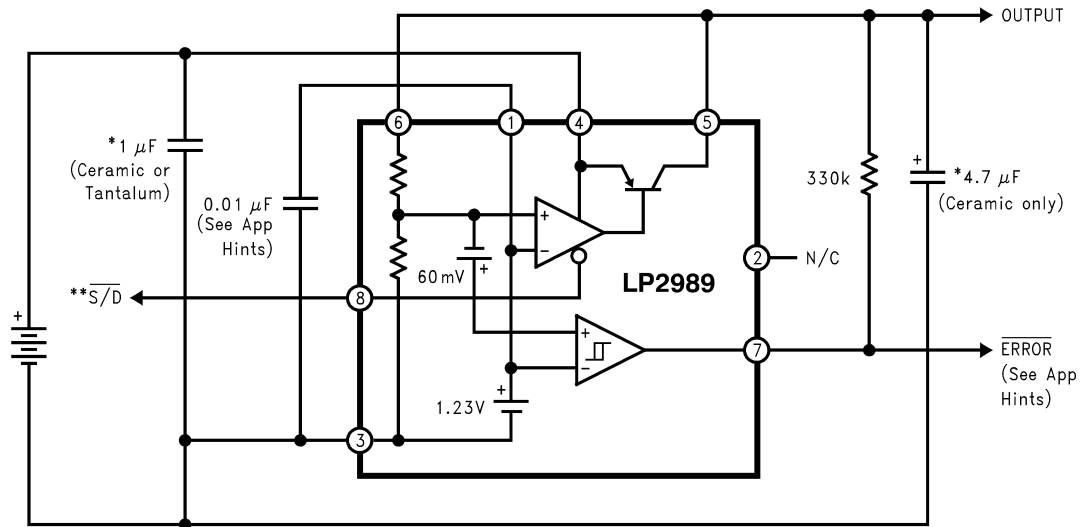


Ordering Information

TABLE 1. Package Marking and Ordering Information for SO-8 (M) Devices

Output Voltage	Grade	Order Information	Package Marking	Supplied as:
2.5	A	LP2989AIMX-2.5	2989AIM2.5	2500 Units on Tape and Reel
2.5	A	LP2989AIM-2.5	2989AIM2.5	Shipped in Anti-Static Rails
2.5	STD	LP2989IMX-2.5	2989IM2.5	2500 Units on Tape and Reel
2.5	STD	LP2989IM-2.5	2989IM2.5	Shipped in Anti-Static Rails

Basic Application Circuit



*Capacitance values shown are minimum required to assure stability, but may be increased without limit. Larger output capacitor provides improved dynamic response.

**Shutdown must be actively terminated (see App. Hints). Tie to INPUT (Pin4) if not used.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	-65°C to +150°C
Operating Junction Temperature Range	-40°C to +125°C
Lead Temperature (Soldering, 5 seconds)	260°C
ESD Rating (Note 2)	2 kV
Power Dissipation (Note 3)	Internally Limited

Input Supply Voltage (Survival)	-0.3V to +16V
Input Supply Voltage (Operating)	2.1V to +16V
Sense Pin	-0.3V to +6V
Output Voltage (Survival) (Note 4)	-0.3V to +16V
I _{OUT} (Survival)	Short Circuit Protected
Input-Output Voltage (Survival) (Note 5)	-0.3V to +16V

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: V_{IN} = V_{O(NOM)} + 1V, I_L = 1 mA, C_{OUT} = 4.7 μF, C_{IN} = 1 μF, V_{S/D} = 2V.

Symbol	Parameter	Conditions	Typical	LP2989AI-X.X (Note 6)		LP2989I-X.X (Note 6)		Units
				Min	Max	Min	Max	
V _O	Output Voltage Tolerance			-0.75	0.75	-1.25	1.25	%V _{NOM}
		1 mA < I _L < 500 mA V _{O(NOM)} + 1V ≤ V _{IN} ≤ 16V		-1.5	1.5	-2.5	2.5	
		1 mA < I _L < 500 mA V _{O(NOM)} + 1V ≤ V _{IN} ≤ 16V -25°C ≤ T _J ≤ 125°C		-4.0	2.5	-5.0	3.5	
				-3.5	2.5	-4.5	3.5	
$\frac{\Delta V_O}{\Delta V_{IN}}$	Output Voltage Line Regulation	V _{O(NOM)} + 1V ≤ V _{IN} ≤ 16V	0.005		0.014		0.014	%/V
					0.032		0.032	
$\frac{\Delta V_O}{\Delta I_L}$	Load Regulation	1 mA < I _L < 500 mA	0.4					%V _{NOM}
V _{IN} -V _O	Dropout Voltage (Note 7)	I _L = 100 μA	1		3		3	mV
					4		4	
		I _L = 200 mA	150		200		200	
					300		300	
		I _L = 500 mA	310		425		425	
					650		650	
I _{GND}	Ground Pin Current	I _L = 100 μA	110		175		175	μA
					200		200	
		I _L = 200 mA	1		2		2	mA
					3.5		3.5	
		I _L = 500 mA	3		6		6	
			9		9			
		V _{S/D} < 0.18V	0.5		2		2	μA
		V _{S/D} < 0.4V	0.05		0.8		0.8	
I _{O(PK)}	Peak Output Current	V _{OUT} ≥ V _{O(NOM)} - 5%	800	600		600		mA
I _{O(MAX)}	Short Circuit Current	R _L = 0 (Steady State) (Note 9)	1000					
e _n	Output Noise Voltage (RMS)	BW = 100 Hz to 100 kHz, C _{OUT} = 10 μF C _{BYPASS} = .01 μF V _{OUT} = 2.5V	18					μV(RMS)
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$	Ripple Rejection	f = 1 kHz, C _{OUT} = 10 μF	60					dB

Electrical Characteristics (Continued)

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: $V_{IN} = V_O(\text{NOM}) + 1\text{V}$, $I_L = 1\text{ mA}$, $C_{OUT} = 4.7\ \mu\text{F}$, $C_{IN} = 1\ \mu\text{F}$, $V_{S/D} = 2\text{V}$.

Symbol	Parameter	Conditions	Typical	LP2989AI-X.X (Note 6)		LP2989I-X.X (Note 6)		Units
				Min	Max	Min	Max	
$\frac{\Delta V_{OUT}}{\Delta T}$	Output Voltage Temperature Coefficient	(Note 8)	20					ppm/ $^\circ\text{C}$
SHUTDOWN INPUT								
$V_{S/D}$	S/D Input Voltage	$V_H = \text{O/P ON}$	1.4	1.6		1.6		V
		$V_L = \text{O/P OFF}$ $I_{IN} \leq 2\ \mu\text{A}$	0.50		0.18		0.18	
$I_{S/D}$	S/D Input Current	$V_{S/D} = 0$	0.001		-1		-1	μA
		$V_{S/D} = 5\text{V}$	5		15		15	
ERROR COMPARATOR								
I_{OH}	Output "HIGH" Leakage	$V_{OH} = 16\text{V}$	0.001		1		1	μA
V_{OL}	Output "LOW" Voltage	$V_{IN} = V_O(\text{NOM}) - 0.5\text{V}$, $I_O(\text{COMP}) = 150\ \mu\text{A}$	150		220		220	mV
					350		350	
$V_{THR}(\text{MAX})$	Upper Threshold Voltage		-4.8	-6.0	-3.5	-6.0	-3.5	% V_{OUT}
$V_{THR}(\text{MIN})$	Lower Threshold Voltage		-6.6	-8.3	-2.5	-8.3	-2.5	
				-8.9	-4.9	-8.9	-4.9	
				-13.0	-3.0	-13.0	-3.0	
HYST	Hysteresis		2.0					

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: ESD testing was performed using Human Body Model, a 100 pF capacitor discharged through a 1.5 k Ω resistor.

Note 3: The maximum allowable power dissipation is a function of the maximum junction temperature, $T_J(\text{MAX})$, the junction-to-ambient thermal resistance, θ_{J-A} , and the ambient temperature, T_A . The maximum allowable power dissipation at any ambient temperature is calculated using:

$$P(\text{MAX}) = \frac{T_J(\text{MAX}) - T_A}{\theta_{J-A}}$$

The value of θ_{J-A} for the SO-8 (M) package is 160 $^\circ\text{C}$. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown.

Note 4: If used in a dual-supply system where the regulator load is returned to a negative supply, the LP2989 output must be diode-clamped to ground.

Note 5: The output PNP structure contains a diode between the V_{IN} and V_{OUT} terminals that is normally reverse-biased. Forcing the output above the input will turn on this diode and may induce a latch-up mode which can damage the part (see Application Hints).

Note 6: Limits are 100% production tested at 25 $^\circ\text{C}$. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's Average Outgoing Quality Level (AOQL).

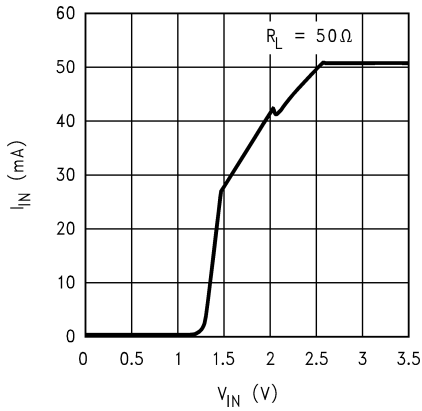
Note 7: Dropout voltage is defined as the input to output differential at which the output voltage drops 100 mV below the value measured with a 1V differential.

Note 8: Temperature coefficient is defined as the maximum (worst-case) change divided by the total temperature range.

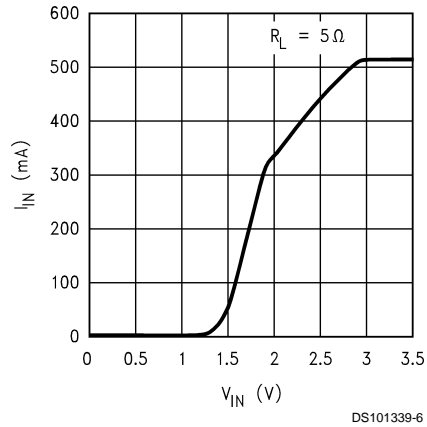
Note 9: See Typical Performance Characteristics curves.

Typical Performance Characteristics Unless otherwise specified: $T_A = 25^\circ\text{C}$, $C_{OUT} = 4.7 \mu\text{F}$, $C_{IN} = 1 \mu\text{F}$, S/D is tied to V_{IN} , $V_{IN} = V_O(\text{NOM}) + 1\text{V}$, $I_L = 1 \text{mA}$, $V_{OUT} = 2.5\text{V}$.

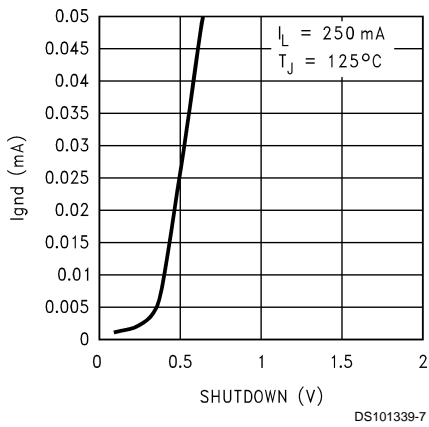
Input Current vs V_{IN}



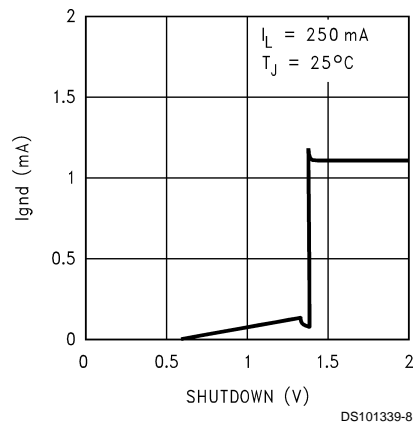
Input Current vs V_{IN}



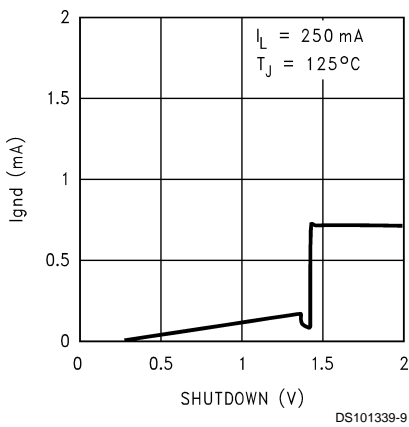
I_{GND} vs Shutdown



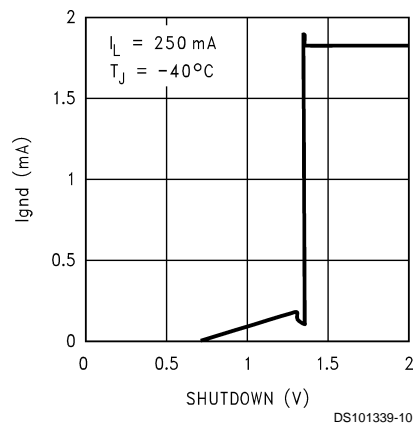
I_{GND} vs Shutdown



I_{GND} vs Shutdown

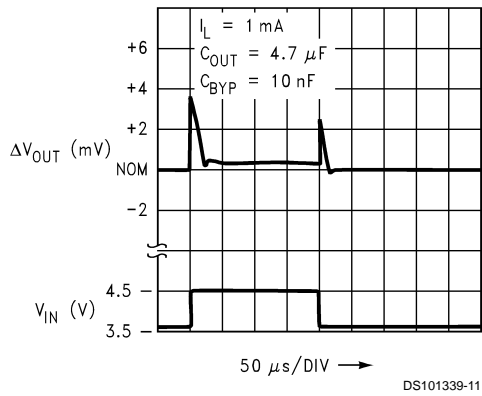


I_{GND} vs Shutdown

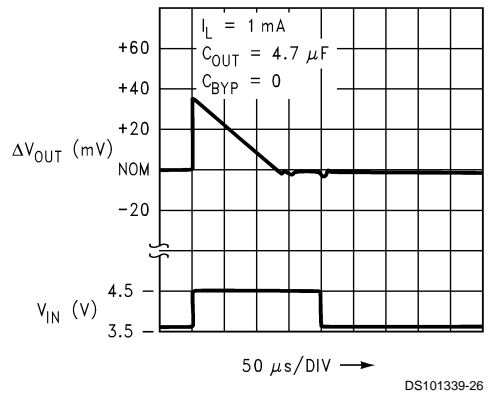


Typical Performance Characteristics Unless otherwise specified: $T_A = 25^\circ\text{C}$, $C_{OUT} = 4.7\ \mu\text{F}$, $C_{IN} = 1\ \mu\text{F}$, S/D is tied to V_{IN} , $V_{IN} = V_{O(NOM)} + 1\text{V}$, $I_L = 1\ \text{mA}$, $V_{OUT} = 2.5\text{V}$. (Continued)

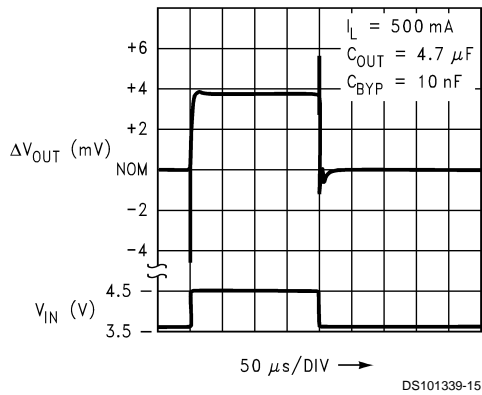
Line Transient Response



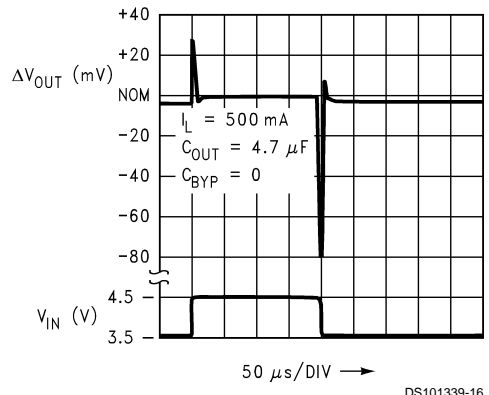
Line Transient Response



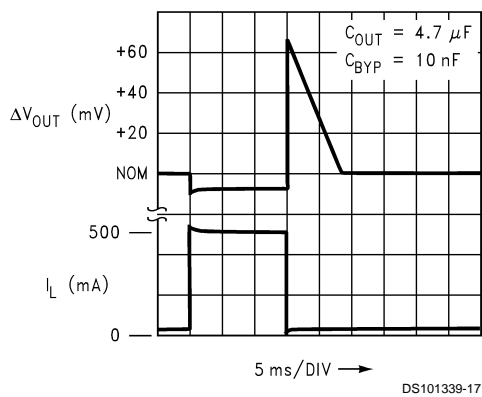
Line Transient Response



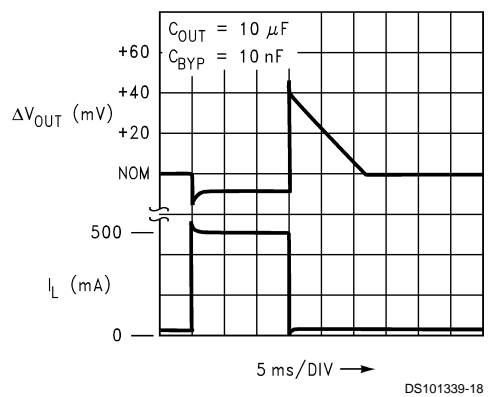
Line Transient Response



Load Transient Response

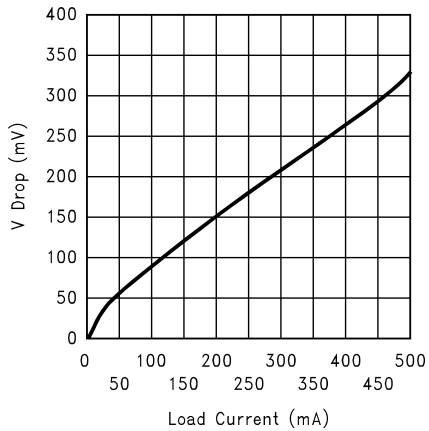


Load Transient Response

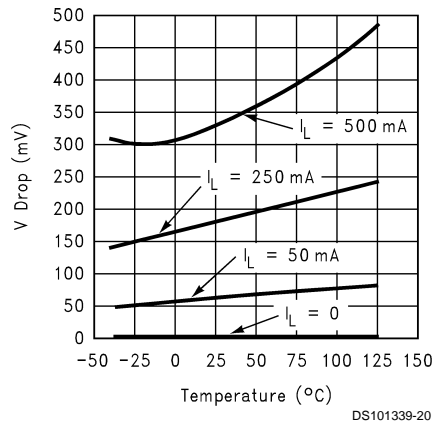


Typical Performance Characteristics Unless otherwise specified: $T_A = 25^\circ\text{C}$, $C_{OUT} = 4.7 \mu\text{F}$, $C_{IN} = 1 \mu\text{F}$, S/D is tied to V_{IN} , $V_{IN} = V_{O(NOM)} + 1\text{V}$, $I_L = 1 \text{mA}$, $V_{OUT} = 2.5\text{V}$. (Continued)

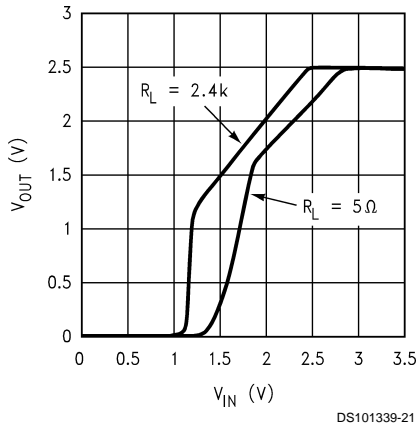
Dropout Voltage vs Load Current



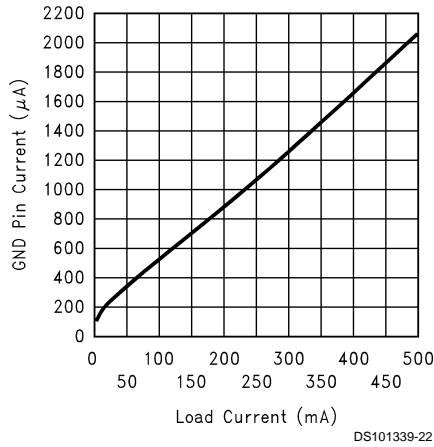
Dropout Voltage vs Temperature



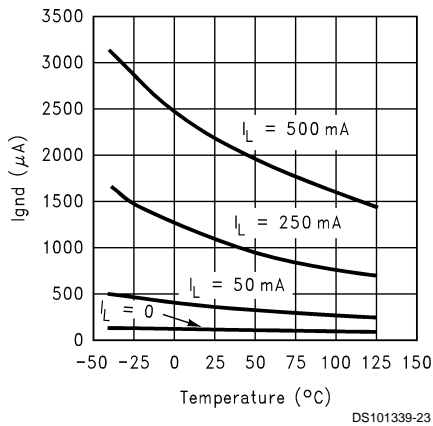
Dropout Characteristics



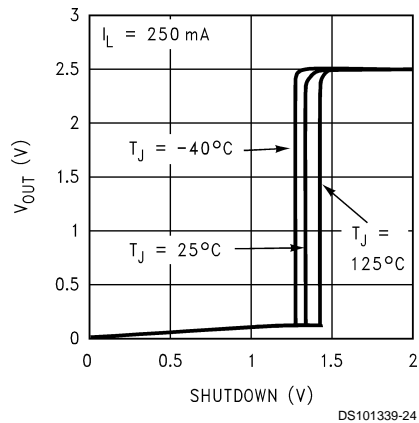
Ground Pin Current vs Load Current



GND Pin Current vs Temperature and Load

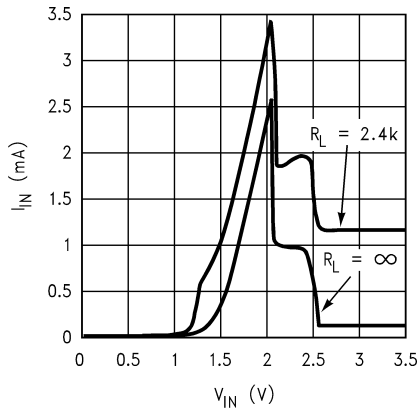


V_OUT vs Shutdown



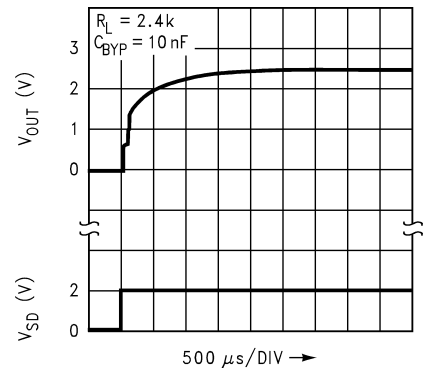
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Input Current vs V_{IN}



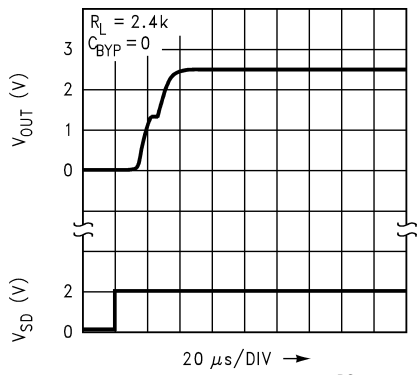
DS101339-25

Turn-ON Waveform



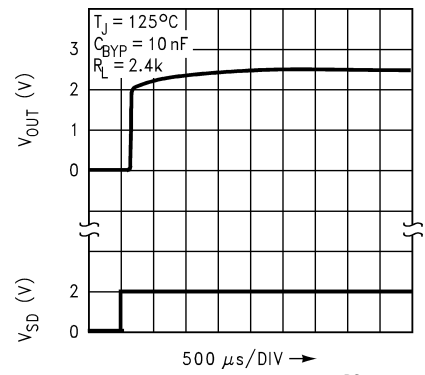
DS101339-28

Turn-ON Waveform



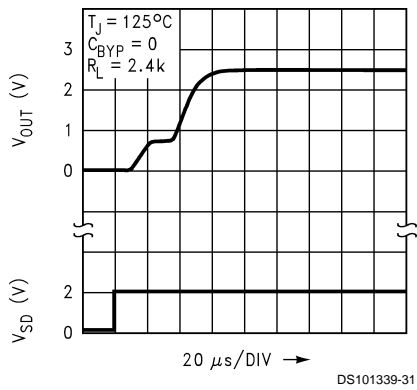
DS101339-29

Turn-ON Waveform



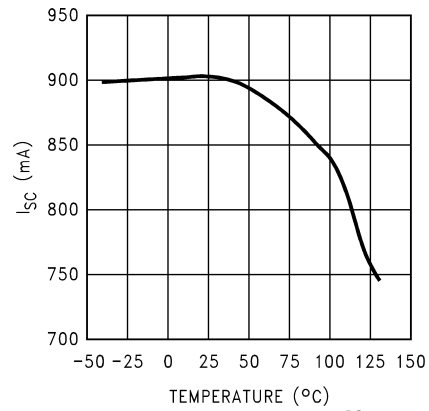
DS101339-30

Turn-ON Waveform



DS101339-31

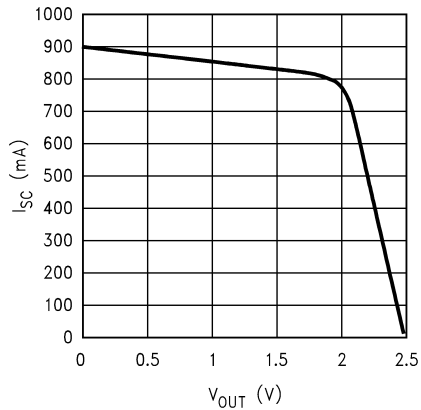
Short Circuit Current vs Temperature



DS101339-32

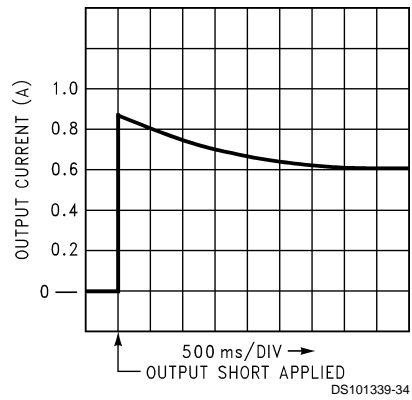
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Short Circuit Current vs V_{OUT}



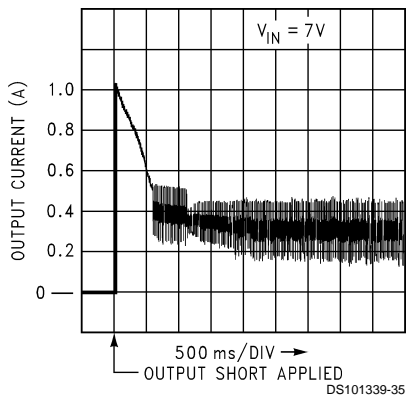
DS101339-33

Short Circuit Current



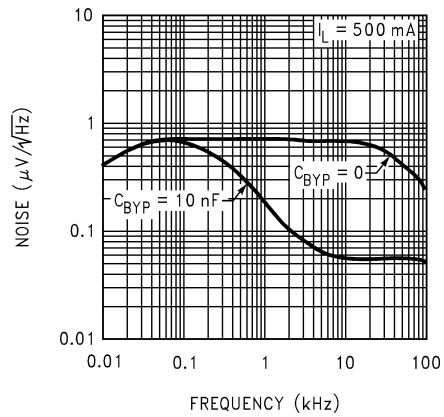
DS101339-34

Short Circuit Current



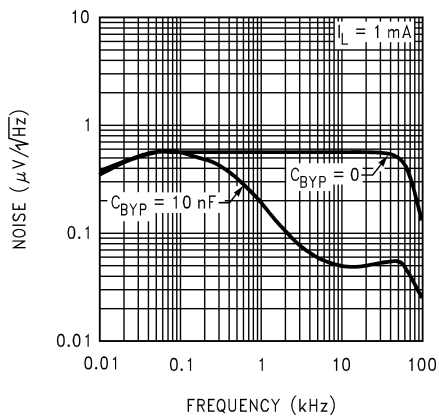
DS101339-35

Output Noise Density



DS101339-36

Output Noise Density



DS101339-37

Application Hints

EXTERNAL CAPACITORS

Like any low-dropout regulator, the LP2989 requires external capacitors for regulator stability. These capacitors must be correctly selected for good performance.

INPUT CAPACITOR: An input capacitor whose capacitance is $\geq 1 \mu\text{F}$ is required between the LP2989 input and ground (the amount of capacitance may be increased without limit).

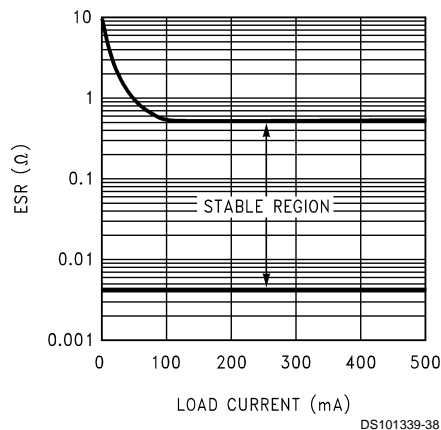
This capacitor must be located a distance of not more than 0.5" from the input pin and returned to a clean analog ground. Any good quality ceramic, tantalum, or film capacitor may be used at the input.

IMPORTANT: Tantalum capacitors can suffer catastrophic failure due to surge current when connected to a low-impedance source of power (like a battery or very large capacitor). If a Tantalum capacitor is used at the input, it must be guaranteed by the manufacturer to have a surge current rating sufficient for the application.

There are no requirements for ESR on the input capacitor, but tolerance and temperature coefficient must be considered when selecting the capacitor to ensure the capacitance will be $\geq 1 \mu\text{F}$ over the entire operating temperature range.

OUTPUT CAPACITOR: The LP2989 is designed specifically to work with ceramic output capacitors, utilizing circuitry which allows the regulator to be stable across the entire range of output current with an output capacitor whose ESR is as low as 5 m Ω . It may also be possible to use Tantalum or film capacitors at the output, but these are not as attractive for reasons of size and cost (see next section Capacitor Characteristics).

The output capacitor must meet the requirement for minimum amount of capacitance and also have an ESR (equivalent series resistance) value which is within the stable range. Curves are provided which show the stable ESR range as a function of load current (see ESR graph below).



Stable Region For output Capacitor ESR

Important: The output capacitor must maintain its ESR within the stable region *over the full operating temperature range of the application* to assure stability.

The LP2989 requires a minimum of 4.7 μF on the output (output capacitor size can be increased without limit).

It is important to remember that capacitor tolerance and variation with temperature must be taken into consideration when selecting an output capacitor so that the minimum required amount of output capacitance is provided over the full

operating temperature range. Some ceramic capacitors can exhibit large changes in capacitance with temperature, so X7R or X5R dielectric are strongly recommended.

The output capacitor must be located not more than 0.5" from the output pin and returned to a clean analog ground.

NOISE BYPASS CAPACITOR: Connecting a 10 nF capacitor to the Bypass pin significantly reduces noise on the regulator output. However, the capacitor is connected directly to a high-impedance circuit in the bandgap reference.

Because this circuit has only a few microamperes flowing in it, any significant loading on this node will cause a change in the regulated output voltage. For this reason, DC leakage current through the noise bypass capacitor must never exceed 100 nA, and should be kept as low as possible for best output voltage accuracy.

The types of capacitors best suited for the noise bypass capacitor are ceramic and film. High-quality ceramic capacitors with either NPO or COG dielectric typically have very low leakage. 10 nF polypropylene and polycarbonate film capacitors are available in small surface-mount packages and typically have extremely low leakage current.

CAPACITOR CHARACTERISTICS

CERAMIC: The LP2989 was designed to work with ceramic capacitors on the output to take advantage of the benefits they offer: for capacitance values in the 4.7 μF range, ceramics are the least expensive and also have the lowest ESR values (which makes them best for eliminating high-frequency noise). The ESR of a typical 4.7 μF ceramic capacitor is in the range of 10 m Ω to 15 m Ω , which easily meets the ESR limits required for stability by the LP2989.

One disadvantage of ceramic capacitors is that their capacitance can vary with temperature. Many large value ceramic capacitors ($\geq 2.2 \mu\text{F}$) are manufactured with the Z5U or Y5V temperature characteristic, which results in the capacitance dropping by more than 50% as the temperature goes from 25°C to 85°C.

This could cause problems if a 4.7 μF capacitor were used on the output since it will drop down to approximately 2.4 μF at high ambient temperatures (which could cause the LP2989 to oscillate). If Z5U or Y5V capacitors are used on the output, a *minimum capacitance value of 10 μF must be observed*.

A better choice for temperature coefficient in ceramic capacitors is X7R or X5R, which holds the capacitance within about $\pm 15\%$ over the operating temperature range.

TANTALUM: Tantalum output capacitors are not recommended for use with the LP2989 because:

Tantalum capacitors are less desirable than ceramics for use as output capacitors because they are typically more expensive when comparing equivalent capacitance and voltage ratings in the 1 μF to 4.7 μF range.

Another important consideration is that Tantalum capacitors have higher ESR values than equivalent size ceramics. This means that while it may be possible to find a Tantalum capacitor with an ESR value within the stable range, it would have to be larger in capacitance (which means bigger and more costly) than a ceramic capacitor with the same ESR value.

It should also be noted that the ESR of a typical Tantalum will increase about 2:1 as the temperature goes from 25°C down to -40°C, so some guard band must be allowed.

FILM: Polycarbonate and polypropylene film capacitors have excellent electrical performance: their ESR is the low-

Application Hints (Continued)

est of the three types listed, their capacitance is very stable with temperature, and DC leakage current is extremely low. One disadvantage is that film capacitors are larger in physical size than ceramic or tantalum which makes film a poor choice for either input or output capacitors.

However, their low leakage makes them a good choice for the noise bypass capacitor. Since the required amount of capacitance is only .01 μF , small surface-mount film capacitors are available in this size.

SHUTDOWN INPUT OPERATION

The LP2989 is shut off by driving the Shutdown input low, and turned on by pulling it high. If this feature is not to be used, the Shutdown input should be tied to V_{IN} to keep the regulator output on at all times.

To assure proper operation, the signal source used to drive the Shutdown input must be able to swing above and below the specified turn-on/turn-off voltage thresholds listed in the Electrical Characteristics section under $V_{\text{ON/OFF}}$.

To prevent mis-operation, the turn-on (and turn-off) voltage signals applied to the Shutdown input must have a slew rate which is $\geq 40 \text{ mV}/\mu\text{s}$.

CAUTION: the regulator output voltage can not be guaranteed if a slow-moving AC (or DC) signal is applied that is in the range between the specified turn-on and turn-off voltages listed under the electrical specification $V_{\text{ON/OFF}}$ (see Electrical Characteristics).

REVERSE INPUT-OUTPUT VOLTAGE

The PNP power transistor used as the pass element in the LP2989 has an inherent diode connected between the regulator output and input.

During normal operation (where the input voltage is higher than the output) this diode is reverse-biased.

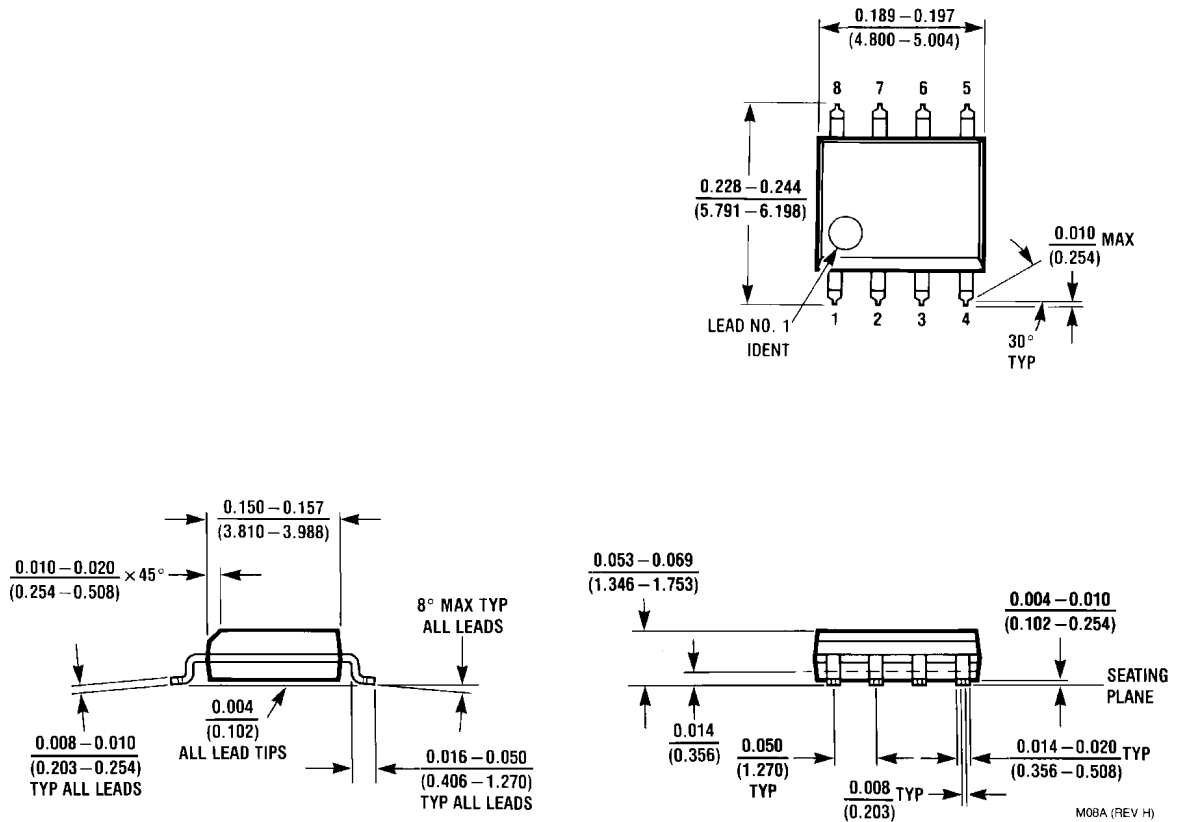
However, if the output is pulled above the input, this diode will turn ON and current will flow into the regulator output.

In such cases, a parasitic SCR can latch which will allow a high current to flow into V_{IN} (and out the ground pin), which can damage the part.

In any application where the output may be pulled above the input, an external Schottky diode must be connected from V_{IN} to V_{OUT} (cathode on V_{IN} , anode on V_{OUT}), to limit the reverse voltage across the LP2989 to 0.3V (see Absolute Maximum Ratings).

**LP2989 Micropower/Low Noise, 500 mA Ultra Low-Dropout Regulator
For Use with Ceramic Output Capacitors**

Physical Dimensions inches (millimeters) unless otherwise noted



**SO-8 Package Type M
NS Package Number M08A**

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